

### ***General Discussion***

This section of the manual provides general definitions and descriptions of non-redundant bridges, fracture-critical members, and fatigue-sensitive details. Additional information on these topics can be found in the references listed at the end of this section.

### ***Non-Redundant Bridges***

Redundancy is the ability of a structural system to redistribute loads to other members should one or more members in the original system fail. Should a member or element fail, the load previously carried by the failed member would be redistributed within the system to other members. The other members would temporarily carry additional load, thereby avoiding collapse of the structure. On non-redundant structures, the redistribution of load causes additional members to fail, resulting in a partial or total collapse of the structure. Bridge designs that are non-redundant have two or fewer main load-carrying members or load paths.

Non-redundant structural systems in the MDOT bridge inventory include two-girder systems and two-truss systems. A two-girder framing system is composed of two longitudinal girders which span between piers with transverse floorbeams between the girders. The floorbeams support longitudinal stringers that, in turn, support the deck. A two-truss system is composed of two longitudinal trusses that span between piers with transverse floorbeams between the trusses. Similar to the two-girder system, the floorbeams support longitudinal stringers that support the deck.



Typical Two-Girder System  
M-37 over Muskegon River



Typical Two-Truss System  
US-2 over Cut River

Most of the members (main girders in the two-girder systems and main trusses in the two-truss systems) in the Non-Redundant subset of bridges are riveted. Extensive research has been done by the National Cooperative Highway Research Program (NCHRP) on the topic of riveted members and internal redundancy. NCHRP Report 302, Fatigue and Fracture Evaluation for Rating Riveted Bridges, discusses

this topic in depth. The report indicates that significant redundancy exists in riveted members because of their use of multiple tensile components -- web, flange angles, and cover plates. Because of their ability to redistribute load without adverse effects, riveted members have significant residual life after cracking occurs. The report concludes that the possibility of fatigue damage in riveted highway structures is low based on the historical positive experience with these types of members having no significant cracking problems. However, in the interest of conservatism, these members should continue to receive close annual inspections

### ***Fracture-Critical Members***

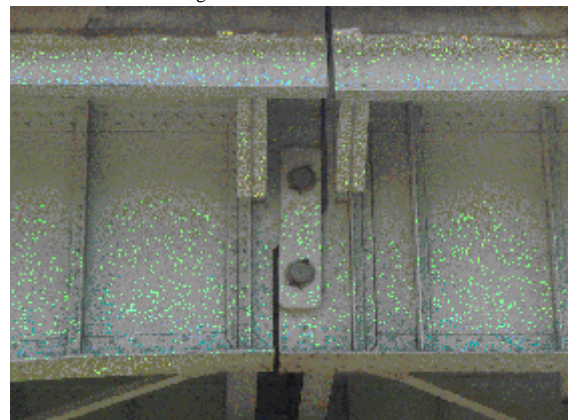
Fracture-critical members (FCMs) are tension members or tension components of members whose failure would be expected to result in collapse of a structure. To qualify as an FCM, the member or components of the member must be in tension and there must not be any other member or system of members that would serve the functions of the member in question should it fail.

In a two-girder (non-redundant) system, the failure of one girder may cause the span to collapse. The non-redundant bridges with fracture-critical members in the MDOT bridge inventory have cantilevered suspended span arrangements. Fracture-critical elements in these bridges include the portions of the girders in tension. These span arrangements cause tension in the top flange and upper portion of the web in areas of the cantilevered spans over the interior support. Tension is induced in portions of the bottom flange and the adjacent portion of the web in areas near the anchored support. See Figure 1.



Typical Cantilevered Suspended Span Arrangement  
M-37 over Muskegon River

In these two-girder systems, a pin and hanger assembly is used to support the suspended span from the cantilevered span. Hangers in a two-girder system offer no redundancy and are considered to be fracture-critical members as well.



Typical Pin and Hanger Assembly  
M-37 over Muskegon River

Fracture criticality in the two-truss systems is similar to that in the two-girder systems. In the area over the interior support, the top chord is in tension and would be considered fracture-critical. In the area near the anchor support, the bottom chord is in tension and would be considered fracture-critical. Diagonal members in tension should also be considered fracture-critical. These tension

members should be identified by an analysis performed by a Structural Engineer. The truss bridges also have tie-down assemblies at the abutments that protect the superstructure against uplift. These assemblies, consisting of pins and links, should also be considered fracture-critical.

**Figure 1. Cantilevered Suspended Span Arrangement**

### *Fatigue-Sensitive Details*

Fatigue is the phenomenon whereby a member would fail at a lower stress when subjected to cyclical loading than when subjected to static loading. Fatigue cracks develop in bridges due to repeated loadings.

Fatigue damage generally occurs at connections, locations of abrupt dimension changes, and surface or internal flaws. Overload conditions, or loadings exceeding those for which the members were designed, can cause overstresses that can potentially lead to crack development (the break occurring in a paper clip after repeated bending back and forth is an example of a fatigue failure). In general, welded bridge details are more susceptible to fatigue failure than riveted or bolted details. Fatigue-sensitive details which are commonly found in the two-girder systems in the MDOT inventory include tack/spot or attachment welds in the tension zones of the girders, welded flange splices, intersecting welds, and small web gaps at diaphragm connection plates. For photographs of typical fatigue-sensitive details, see the Inspection Methods Section of this manual.

Tack/spot welds are usually temporary welds used to hold components of built-up sections together during erection. These welds are generally removed after they are no longer needed. Sometimes, however, they are left in place and can provide a stress concentration that might be susceptible to fatigue cracking. Similarly, attachment welds for various items such as gusset plates or downspouts for deck drainage systems can provide stress concentrations in the tension areas of a girder.

Welded splices in the tension flanges of girders and any intersecting welds could include internal flaws which would produce a stress concentration.

The small web gaps that exist at locations where connection plates are not rigidly attached to the flanges may not provide adequate flexibility for the webs to accommodate out-of-plane bending stresses. The ends of the connection plates provide hard spots for the web to bend around, potentially causing cracking.

Welded details are categorized in descending order of fatigue strength from Category A to Categories E and E'.

- ! Category A details are for base metal or plain material away from welded, riveted, or bolted connections. This category provides the highest fatigue strength of structural members.
- ! Category B details include longitudinal continuous welds in built-up shapes, such as web-to-flange connections, fillet welds at longitudinal stiffeners (except at the ends), and fillet welds joining cover plates to girder flanges (except at the ends). Also included are transverse full-penetration groove welds such as flange and web splices.
- ! Category C details include transverse stiffeners, intersecting plates connected by fillet welds, and very short attachments (gusset plates, etc.)

- ! Category D details include welded short attachments and welded connections with sharp transition curves.
- ! Category E and E' details include ends of partial length cover plates and welded attachments with loads transverse to the welds.

See Figure 2 for typical details. Also, see references listed at the end of this section for additional information.

**Figure 2. Typical Weld Details**

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### ***Inspection Program***

This section of the manual provides a general discussion of the inspection program and discusses typical types and causes of deterioration which are significant for fracture-critical members and fatigue-sensitive details. Typical methods of inspection and signs of deterioration or potential problems are also discussed.

#### ***General***

A close hands-on inspection of the fracture-critical members and fatigue-sensitive details discussed in this manual is of the utmost importance when performing the inspection of these structures. It is often difficult to see a crack just beginning to form without observing the area from a short distance. It is recommended that a Reach-All or other underbridge inspection equipment such as a bucket truck be used to access these critical areas. Detailed inspections should be conducted at no more than arms length from each feature. For more information, refer to the Visual Inspection Section of this manual.

A general NBIS inspection of the Big 12 bridges should be made on a biennial basis. Fracture-critical members and fatigue-sensitive detail inspections discussed in this manual should be performed annually.

The most common types of material deterioration of the steel members discussed in this manual are corrosion and cracking.

Corrosion, with its associated deterioration of steel members and section loss, can lead to a substantial reduction in member capacity. Areas especially vulnerable to corrosion are locations where moisture can be trapped against the surface of the steel and where drying is slow. Typical problem locations include areas under deck joints, around deck drains and drain pipes, on flat surfaces or under areas where debris can accumulate, on exposed surfaces of fascia members, on steel in contact with concrete, at overlapping steel plates, and at corners of steel angles and channels. Corrosion build-up can also freeze moving parts, such as those found in pin and hanger assemblies and bearings.

Crack initiation generally occurs at a stress concentration. Stress concentrations may be located at material defects such as a slag inclusion in a weld or a nick or gouge in a steel plate. They also occur at sudden changes in the cross section of the member, such as at the ends of cover plates or at intersecting welds where two or more components of a built-up section meet or cross. Fatigue cracks are also commonly caused by distortion in girder webs at locations where the diaphragm or crossframe connection plates are not rigidly attached to the flanges. The small gaps allow this distortion due to differential deflections of the beams. As the ends of the diaphragm rotate, a crack may form in the web at the upper or lower ends of the connection plate. For more information, see the Inspection Methods Section of this manual.

It is imperative that any suspicious conditions or items of concern regarding fracture-critical bridge elements be reported immediately to the Bridge Design Division in Lansing. If a crack is found in a fracture-critical

member, corrective actions may be necessary immediately. If uncertain, the inspector should seek guidance from the Construction and Technology or Design Divisions. The inspector can expect to be required to obtain further information about the given circumstances that will allow the designer to structurally analyze the problem.

After the Design Division has detailed the specific repair to be performed, the Region must decide who will perform the repairs and how they will be executed. The Region Bridge Crews may wish to do the repairs or they may want to have the Statewide Crew help with the work. The Design Division will advise based on the degree of complexity and size of the project.

Using MDOT forces to make repairs is often preferred because of the relatively short response time in which they can act. However, some cases may require a contract with a contractor. In this case, MDOT forces may be used to effect temporary repairs.

Non-redundant fracture-critical bridges, like all bridges, have other elements, such as joints and bearings, that are essential to the proper performance of the structural system. These elements, while not fracture-critical members themselves, impact the performance of fracture-critical members. For example, a leaking joint could promote corrosion in a pin and hanger assembly. It is important to carefully inspect these bridge elements as well; the inspections should be performed in accordance with guidelines set forth in the FHWA Bridge Inspector's Training Manual.

The bridges are inspected for NBI rating on a 24-month inspection cycle. However, select areas of the bridges are inspected every year. It is recommended that the official inspection frequency may remain as 24 months, but that the Regions continue to check the bridges every year.

### *Inspection Methods*

The tension areas of fracture-critical members and all fatigue-sensitive details should be carefully visually inspected for cracks, section loss due to corrosion, and other forms of distress. Suspected cracks should be verified and their limits determined by non-destructive methods. Cracks in fracture-critical members are potentially very serious flaws, possibly leading to bridge failures. Corroded areas should be thoroughly cleaned to facilitate inspection for cracks and to determine the extent of the loss of section in the member.

Most cracks are detected by visual inspection and are usually found at locations where paint is cracked or where rust stains have developed. Cracks often have propagated to a depth between one-fourth and one-half the plate thickness before the paint film has broken. However, the mere presence of broken paint film does not necessarily mean that a crack has formed in the underlying steel. Paint in the surrounding areas should be removed using a wire brush or grinding to clearly see the steel. Any suspected cracks should be verified, and their extents determined by non-destructive means. Spot painting should be

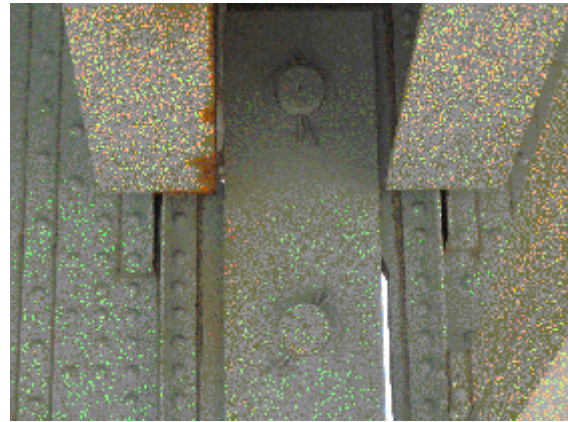
scheduled after the testing has been completed.

The following locations should be carefully checked for cracks or significant section loss, as applicable. Specific locations for each bridge are listed in the individual bridge sections at the end of this manual.

### ***Fracture-Critical Members/Fatigue-Sensitive Details***

! **Pin and hanger assemblies.** Pin and hanger assemblies are critical components in a bridge structural system. The pins rotate under live load and thermal expansion and tend to wear over time. The hangers are in tension and are susceptible to fatigue and fracture, especially if the pins become frozen due to the buildup of corrosion. The small gaps between the components of the pin retainer mechanism allow dirt and rust buildup that is not easily detected. This condition could cause unintended fixity, which would cause the pins to seize up and produce in-plane bending stresses in the hanger and torsional forces in the pin. High out-of-plane impact loads may result when the mechanism periodically breaks free. Expanding corrosion could also force the hanger plates out of alignment, and they may fail the cotter pins in the retainer mechanism and “walk” off the pin, causing catastrophic collapse.

The pins and hangers should be carefully inspected for cracks and section loss. Wear in the pins and hangers generally occurs in two locations: 1) at the top of the pin and the top of the hanger on the cantilevered span, and 2) at the bottom of the pin and the bottom of the hanger on the suspended span. Wear can be measured using the following procedure. Locate the centers of the pins and measure the distance between them; compare to plan dimensions or previous measurements, allowing for any tolerances for machining of the pins and holes. The increase in length is the total apparent wear on both pins and/or hangers. Section loss in the hangers should be measured by use of calipers and documented.

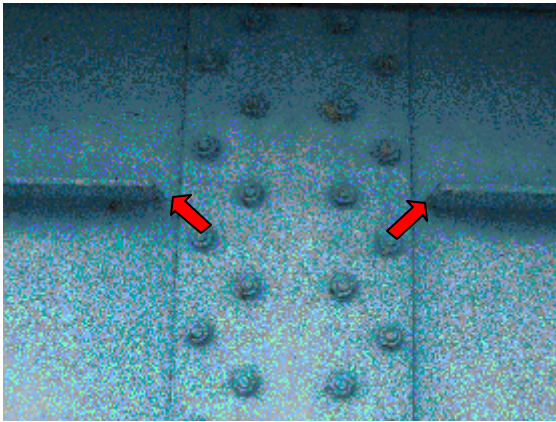


Pin and Hanger Connection  
M-37 over Pine River

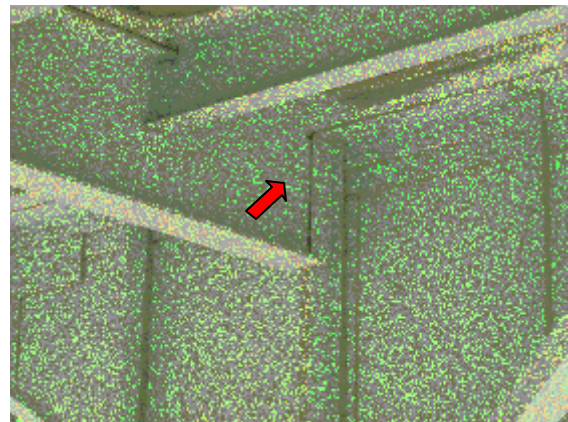
As noted above, any confirmed defects should be reported to the Design Division, Special Assignment Structure Unit. All information should be documented and a copy kept in the bridge files for comparison and reference during future inspections. MDOT should continue the practice of inspecting the pin and hanger assemblies on an annual basis. Pins should be tested ultrasonically at a maximum interval of four years (during alternating biennial inspections).

! **Two-girder systems.** The fracture-critical members in a two-girder system are the main

longitudinal girders into which the floorbeams frame. In welded members, inspections for cracking should take place on the following components: flange and web splices, transverse web stiffeners and connection plates at connections to the web, longitudinal web stiffeners, cover plates, longitudinal fillet welds, the entire length of tension flanges and web, and tack or erection welds. In riveted or bolted members, inspections for cracking should take place on the following components: misdrilled holes that have been repaired with weld metal, areas around floorbeam and lateral bracing connections, the entire length of tension flanges and webs, tack or erection welds, and rivets/bolts and rivet/bolt holes.



Typical Welded Longitudinal Web Stiffeners  
US 10 over Sanford Lake



Typical Riveted Floorbeam Connection to Web  
M-37 over Pine River

### ! Girder webs at floorbeam and diaphragm

**connections.** The tension portion of a web where movement is restricted by the presence of floorbeam, diaphragm or crossframe connection plates is a common location for cracks to develop. The small web gaps that exist at locations where the connection plates are not rigidly attached to the flanges may not provide adequate flexibility to accommodate out-of-plane bending stresses. Two-girder systems are more susceptible to this problem since they do not have the rigidity provided by multi-girder framing. The floorbeams would deflect under live loads, causing the floorbeam ends to rotate. The rotation would cause the girder webs to attempt to distort out of the plane of the web and may result in cracking in the web at the bottom of the connection plate. The portions of the web in the area of the small web gaps should be carefully inspected for cracks. For typical details, see photos and Figure 3.

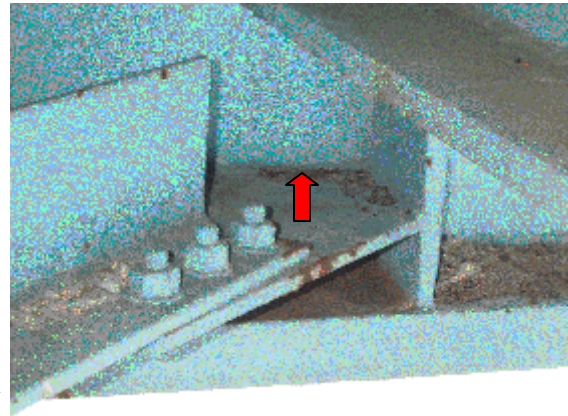


Typical Web Gap at Top of Connection Plate  
US 10 over Sanford Lake



**Figure 3. Typical Web Gap Crack Development**

- ! **Lateral bracing gusset plates on girder webs at floorbeam connections.** Areas around horizontal connection plates used to connect lateral bracing members are susceptible to cracks. Cracks associated with these plates normally begin at the toe of the weld at the end of the plate and grow into the flange or web. The cracks then usually propagate through the thickness of the web and vertically across the web or horizontally across the flange. The intersection of horizontal and vertical welds attaching stiffeners and gusset plates to webs is also a detail prone to fatigue cracking.



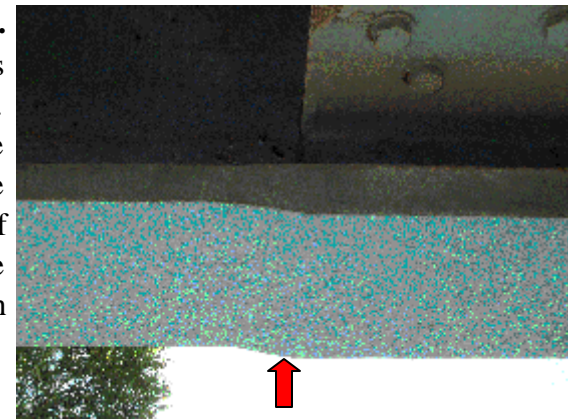
Welded Lateral Bracing Gusset Plate Connection  
US 10 over Sanford Lake

- ! **Welded attachments.** Attachments for utilities or drainage details are sometimes made to the webs or flanges of girders. These welded attachments should be carefully examined, especially if in the tension zone of a member. Bridge crews should never weld on any of these structures without approval from the Design Division and a Qualified Weld Procedure.



Welded Attachment of Downspout Support Rod to Flange  
US 10 over Sanford Lake

- ! **Ends of welded cover plates/flange splices.** Abrupt changes in a section produce stress concentrations that are susceptible to cracking. Cracks normally initiate in the tension flange, at the point where the section changes, and propagate into the weaker section. The termination point of welded cover plates and welded flange splices are common locations for this to occur, and all such locations should be carefully inspected.



Typical Welded Flange Splice  
US 10 over Sanford Lake

- ! **Web stiffeners and intersecting welds.** Girder webs are often designed to be as thin as possible with buckling controlled by the addition of stiffeners. The stiffeners cause a discontinuity in the member and are potential sites for crack development. Transverse and longitudinal stiffeners should be inspected closely in the tension regions of the girders. Cracks normally occur at the ends of the stiffeners. Other areas that are highly susceptible to fatigue cracks are locations where welds of transverse and longitudinal stiffeners to the web intersect and locations where longitudinal web stiffeners may be butt-welded.

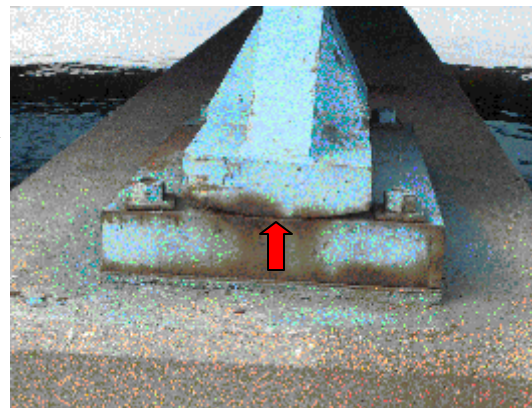


Typical Intersecting Welds  
US 10 over Sanford Lake

- ! **Tack or erection welds.** Tack welds are commonly used in construction of riveted or built-up members to temporarily hold pieces together until bolts, rivets, or permanent welds are in place. Tack welds produce small stress concentrations in the base metal and are susceptible to cracking. Due to their temporary nature, tack welds are not quality tested and are more likely than other welds to contain defects that make them more susceptible to cracking, even in areas of low stress. Tack welds should be carefully inspected whenever they exist on fracture-critical members and, if possible, should be removed by grinding.
- ! **Tie-downs at truss abutments.** These pin and link assemblies serve to anchor the trusses in the end spans of the truss bridges. They should be carefully inspected for cracks and loss of section and to ensure that they are free to move as intended.

### *Other Typical Defect Types/Maintenance Problem Areas*

- ! **Bearings.** Bearing areas and substructure unit integrity should be carefully inspected. Bearings should be checked to ensure that expansion bearings are free to slide or rotate as designed. The curved surfaces on rocker bearings should be checked for the presence of pack rust, dirt, or other debris that may prevent them from moving properly. When a frozen movable bearing at one end of a beam or girder is encountered, the fixed bearing at the other end should also be carefully inspected to ensure that no distress is caused by



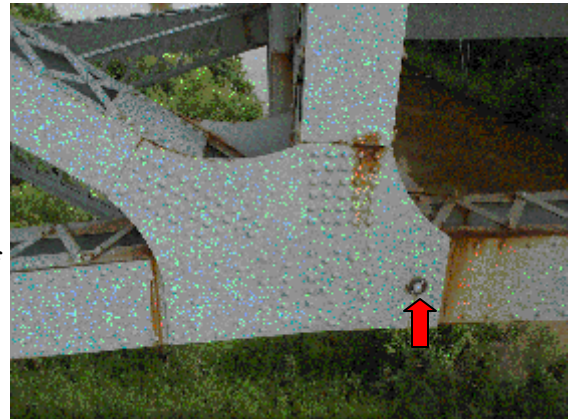
Typical Rocker Bearing  
US 10 over Sanford Lake

the lack of movement. Measurements of the bearing

alignment should be taken along with the temperature of the steel at the time of measurement. Bearing pads or pedestals should be inspected to ensure that proper seating and alignment of the bearing exists. Substructure unit faulting may induce unintended loads into the superstructure, possibly overstressing one or more members.

! **Joints.** Expansion joints in the bridge deck should be inspected to ensure they are free to move properly and are not filled with dirt or debris. Measurements of the joint openings should be taken along with the temperature of the steel at the time of measurement. They should be checked to determine whether they are watertight. Significant steel corrosion or paint failure below an expansion joint is an indicator that the expansion joint is leaking.

! **False chord pins in trusses.** The bottom chord members (L10L11 and L11L12) in the suspended portions at the center of the main spans of the truss bridges are zero-force members. They are commonly referred to as “false chords” because they do not carry load. Their connections to the cantilevered portions of the trusses consist of pins in slotted holes to allow for movement. This movement can cause wear in the pins and they should be inspected closely to ensure that they retain enough section to support the chord members. Any significant wear (more than 10 percent of section) should be documented and reported to the Bridge Design Division.



Typical False Chord Joint  
M-55 over Pine River

### *Non-Destructive Testing*

Non-destructive testing methods are typically used to confirm the presence of a fatigue crack. These methods include, but are not limited to, dye penetrant, ultrasound, magnetic particle, acoustic emission, and radiography. Dye penetrant and ultrasonic testing are the most frequently used to detect cracks in members similar to those in the MDOT's inventory.

Dye penetrant testing is used to determine the extent of surface flaws in steel members. The test area is cleaned to bare metal. A dye is applied and allowed to penetrate the surface. A developer is then applied to draw the dye out of surface irregularities and the extent of the flaw is then defined. This method is

commonly used by bridge inspectors in the field. All inspectors should be trained to use this simple and inexpensive testing method and should have the necessary equipment available to perform this test whenever inspecting these bridges.

Ultrasonic testing involves high frequency sound waves introduced into the material to be tested by a sending transducer. Discontinuities in the specimen interrupt the sound wave and deflect it toward a receiving transducer. The magnitude of the return signal allows measurement of the flaw size. This method is frequently used to detect cracks in welds or pins, where the material to be inspected is not easily accessible, or when flaws exist within the material and are not visible.

### ***Maintenance Program***

This section of the manual discusses the purpose and advantages of a program of regularly scheduled maintenance. It also discusses suggested maintenance activities which should be performed for these bridges.

#### ***Purpose of Maintenance Program***

The MDOT has successfully maintained these bridges, which at the time of these site visits were found to be generally in better condition than most others of this type in other states. The excellent condition of the bridges is directly related to the increased level of attention paid to them. Maintenance activities have been performed conscientiously, and inspections have been performed frequently to prevent problems from becoming unmanageable. It is recommended that the practices traditionally employed by MDOT be continued by the Regions. Bridges maintained on a regular basis stay in good condition for longer periods, reducing the need for costly repairs that can be avoided through preventative maintenance.

#### ***Scheduled Maintenance Activities***

- ! General bridge washing.** The bridge superstructures should be power-washed on a regular basis to remove accumulations of deicing chemicals, bird droppings, and other debris that might contribute to the breakdown of the protective coatings on the steel and allow corrosion to form. This should be done yearly.
- ! Joint flushing.** The bridge deck joints should be flushed regularly to remove accumulations of dirt and debris that might prevent the joints from opening and closing properly. Excessive debris in the joints can cause tearing of the seals, which could initiate or cause leaks even when the amount of debris is not sufficient to interfere with movement. During the flushing operations, the joints should be inspected for leaks. This should be done yearly.

- ! **Deck drain cleaning.** The bridge deck drainage system should be cleaned regularly to remove dirt and debris accumulations in the deck drains and clogs in the downspouts. Clogs allow standing water to accumulate and corrosion to form on these steel components and tend to cause increases in chloride concentrations, which can aggravate corrosive conditions. The systems should be flushed and checked for leaks. This should be done yearly.
  
- ! **Bearing cleaning.** Bearings should be cleaned of debris and buildup of rust on an annual basis to allow for proper movement. Base plate edges should be caulked with a sealant where they contact the concrete surface. Spot painting should be done annually as required.
  
- ! **Pin and hanger cleaning.** Pin and hanger assemblies should be cleaned of debris and buildup of rust on an annual basis to allow for proper movement. The edges of pin plates should be caulked with a sealant to prevent crevice corrosion. Spot painting should be annually done as required.
  
- ! **Spot painting.** Corroded areas on the superstructure members should be spot cleaned and painted to prevent significant section loss from occurring. Painting should be completed after the annual inspections so that the new paint would not cover defects that should be included in the inspection. Edges of built-up plates should be caulked with sealant to prevent crevice corrosion. This should be done every 3 to 4 years, as required. For bridges painted since 1991, contact Construction & Technology, Bridge Operations for advice.
  
- ! **Crack sealing and spall patching.** Areas of concrete deterioration, especially those on decks and bearing areas, should receive attention to prevent significant section loss from occurring. For example, small cracks and spalls on bearing pads left unrepaired could grow larger, leading to a loss of bearing area. Also, cracks in a deck wearing surface provide a means for deicing chemicals and water to reach the reinforcing steel, causing corrosion with section loss in the steel and spalling in the concrete. Cracks wider than 0.020 inch (20 mils) should be sealed, and spalls should be patched on an annual basis. Areas to be repaired should be noted in the annual inspection reports, and repairs should be made as soon as possible thereafter.

### ***Reference Materials***

This manual is intended to serve as a supplement to other references commonly used by bridge inspectors. These FHWA publications should continue to be used as the guiding documents for the inspection of these structures and are sources of valuable information for bridge inspectors.

- ! *Bridge Inspector's Training Manual/90* (FHWA-PD-91-015).

- ! *Inspection of Fracture Critical Bridge Members* (FHWA-IP-86-26).
- ! *Manual for Inspecting Bridges for Fatigue Damage Conditions* (FHWA-PA-89-022 & 85-02).

There are also several valuable resources within MDOT. The following is a list of locations within MDOT accompanied by the information that is available at each location. Often, however, information is available from several sources. In these cases, only the office or location responsible for that specific information is listed here.

### **Lansing Bridge Design Division**

#### **Personnel**

- ! Special Assignments, Structures Engineer.
- ! Bridge Management Engineer.
- ! Bridge Technology Engineer.

#### **File System**

- ! Microfilmed plans of construction and rehabilitation contract plans.
- ! Full-size plans of recent contracts yet to be microfilmed.
- ! Design project files for contracts not yet sent to the Record Center (older project files can be requested from the Record Center, through the Design File Supervisor).

#### **Bridge Management Unit**

- ! Structural analyses for live load capacity of each bridge.

#### **Special Assignment Structure Unit**

- ! Status of recent and future contract work.
- ! Costs of recent contract work (informal).

### **Lansing Maintenance Division**

#### **Bridge Section**

- ! Folders with historical and miscellaneous information for each bridge (informal).

#### **Statewide Bridge Maintenance Crew**

- ! Miscellaneous bridge maintenance plan sheets (informal).

- ! Verbal history (informal).

## **Lansing Construction and Technology Section**

### **Personnel**

- ! Structural Research Engineer.

### **Library**

- ! Special Investigation Reports.

## **Region Offices**

### **Personnel**

- ! Bridge Engineer.
- ! Bridge Inspector.
- ! Bridge Superintendent.
- ! Bridge Foreman.

### **Documents**

- ! Biennial Inspection Reports.
- ! Fracture-Critical Inspection Reports.